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SATELLITE VACUUM VESSEL
PRESSURE RATING AND RELIEF PORT SIZE

PREPARED UNDER FERMILAB SUBCONTRACT NO. 94199
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FOR

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Drawing 2340-D shows the installation of the pressure relief port on the valve box. The 2 in. pipe protrudes through the insulation and provides clear access to the vacuum space inside the insulation. Drawing 2342-D and Figure 1 shows the details of the relief port. Gas flows through the 2 in. pipe flange and skirt to the outside world.

2. PRESSURE DROP IN RELIEF PORT:

Pressure drop consists of:

a) Entry into pipe with contraction. Assume $1/2\ \rho v^2$ based on 60% of the flow area.

b) 90° turn from pipe to radial flow. Assume $1/2\ \rho v^2$ based on flow area of $\pi D_1 \times h$.

c) 90° turn from radial to downward flow. Assume $1/2\ \rho v^2$ based on flow area of $\pi D_2 \times h$.

$D_1 = 2.157$ in.

$D_2 = 4.75$ in.

$h = .5$ in.

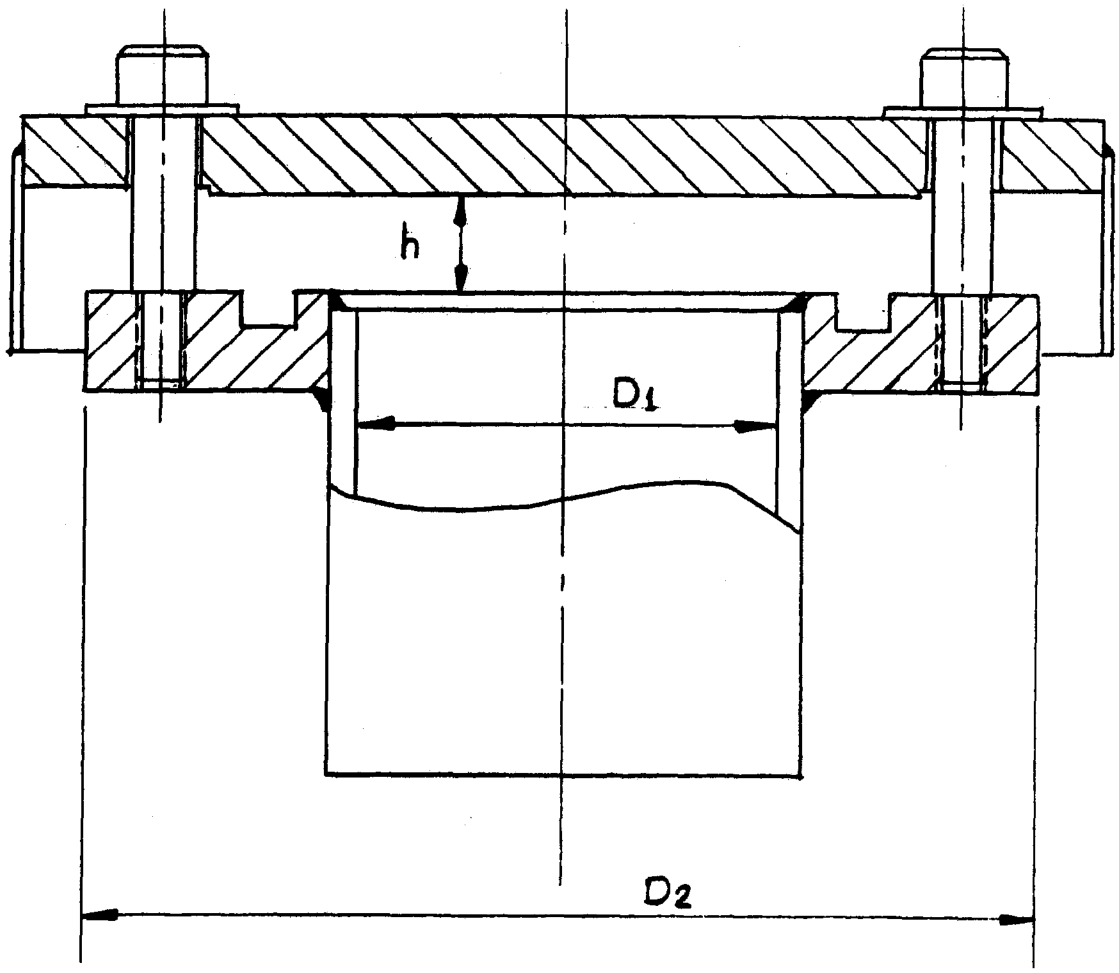

FIGURE 1

$$\text{Area } A_1 = .6 \times 1/4\pi \times 2.157^2 = 2.19 \text{ sq in.}$$

$$A_2 = \pi \times 2.157 \times .5 = 3.39 \text{ sq in.}$$

$$A_3 = \pi \times 4.75 \times .5 = 7.46 \text{ sq in.}$$

$$\Delta P = 1/2\ \rho_1 V_1^2 + 1/2\ \rho_2 V_2^2 + 1/2\ \rho_3 V_3^2$$

Because of limited heat transfer at high flow rates, we will assume that:

$\rho_1 = \rho_2 = \rho_3$ for $\Delta P = 0$

We find then:

$$\Delta P = 1/2\rho\ (V_1^2 + .417\ V_1^2 + .086\ V_1^2)$$

$$= .752\ \rho V_1^2$$

At high flow rates, the total pressure drop may approach 15 psig. In that case, we will assume that:

$$\rho_1 = 1.5\ \rho_2 = 2\rho_3$$

The expression for ΔP at high flow rates then becomes:

$$\Delta P = 1/2\{\frac{M_1^2}{A_1^2\rho_1} + \frac{M_1^2}{A_2^2\rho_2} + \frac{M_1^2}{A_3^2\rho_3}\}$$

$$= 1/2\ \frac{M^2}{\rho_1}\ \{\frac{1}{A_1^2} + \frac{\rho_1}{\rho_2 A_2^2} + \frac{\rho_1}{\rho_3 A_3^2}\}$$

$$= 1/2\ \frac{M^2}{A_1^2\ \rho_1} \left\{ 1 + \left(\frac{A_1}{A_2}\right)^2 1.5 + \left(\frac{A_1}{A_3}\right)^2 2 \right\} = \frac{M^2}{A_1^2\ \rho_1}\ (.9)$$

$$= .9\ \rho_1\ V_1^2$$

Calculate the combination of flow rates and temperatures for which ΔP = 9.5 psig. Table I provides the data:

TABLE I

ΔP Psig	T °K	ρ_1 g/cc	V_1 cm/sec	V_{sonic} cm/sec	$\dot{M}$ g/sec
9.5	6	.0216	4,538	12,790	1,384
9.5	8	.0137	5,699	15,990	1,102
9.5	10	.0104	6,540	18,320	960
9.5	15	.0066	8,210	22,870	765
9.5	20	.0049	9,529	26,500	659
9.5	25	.0039	10,680	29,650	588

3. HIGH PRESSURE LINE BREAK:

How much flow could we obtain from a break in the high pressure line downstream of the coldest exchanger? The gas has to flow from ambient temperature through the tubing of the complete heat exchanger train. Normal flow is of the order of 55 g/sec. Pressure drop associated with this is of the order of 8-10 psig. Pressure drop will be proportional with flow rate to the 1.8 power. Total pressure drop available is approximately 270 psig. Maximum flow rate is then:

$$\left\{ \frac{M_1}{M_2} \right\}^{1.8} = \frac{270}{8} = 33.75$$

$$M_1 = 7.06\ M_2 = 7.06 \times 55 = 388.3\ \text{g/sec}$$

The heat exchanger train limits the flow rate in this case to less than 400 g/sec.

4. CONNECTION BETWEEN HORIZONTAL COLD BOX AND VALVE BOX:

The relief port is located in the valve box. It is conceivable that a high pressure line breaks in the heat exchanger box. In that case, the gas needs a clear and free passage to the valve box. The connecting line is a 6 in. IPS, Schedule 10 (st.stl. 304) pipe. Six relatively small lines are carried in this jacket. These lines are enclosed in a wrapping of superinsulation. Two conditions need to be satisfied in order to assure free passage:

a) The insulation needs to remain in place, and it should not be possible to dislodge it and jam it into the flow passage.

b) All large flow leaks should occur inside the super-insulation. Flowing through the insulation would result in dislodging of the insulation.

To make sure that insulation remains in place, pressure drop in the flow channel should be low. Consider a flow rate of 1,100 grams per second (at least for a short period of time) at 8°K. Assume that pressure in the channel is 15 psig.

Assume that the connecting link is 12 ft long, with one 90° turn and an entrance lo: ɔf 1/2 ρv^2. Total pressure drop in the connecting line then:

$$\Delta P = \frac{f\, {G^1}^2}{193\rho d_h} L + \rho v^2$$

$$G^1 = \frac{G}{3600}$$

Consider an open flow area of 6 sq in. with d_h = 2.4 in.

Then: $M = \frac{1100 \times 3600}{454} = 8{,}722$ lb/hr

$$G = \frac{8722}{6} \times 144 = 209{,}339 \text{ lb/hr ft}^2$$

$$\rho = 1.35 \text{ lb/cft}$$

$$\mu = .005$$

$$Re = 8.37 \times 10^6$$

$$f = .0019$$

$$\frac{\Delta P}{L} = .01 \text{ psig} = .01 \text{ psig}$$

$$\rho v^2 = .348 \text{ psig}$$

Total pressure drop = .47 psig. With insulation wrapped on a heavy mylar cylinder, it appears permissible to generate approximately .5 psig in pressure drop.

5. LOW PRESSURE LINE OR HEAT EXCHANGER SHELL FAILURE:

The low pressure system flow rates cannot exceed those of a high pressure system break, because:

a) The low pressure system in the warm piping is protected to relief at full compressor flow rate at a pressure below 15 psig.

b) A magnet quench does not affect the low pressure system very much.

c) Loss of vacuum will result in a high boil-off rate of the two-phase helium system. Inventory in this system is low and impedance to flow large.

6. CONCLUSIONS AND RECOMMENDATIONS:

a) It appears that the safety relief port in the valve box is adequate for maintenance of a pressure of 15 psig or less in the valve box and horizontal cold box in case of a complete high pressure line break.

b) The insulation in the connecting pipe between valve box and horizontal cold box needs to be secured in such a way that an open passage of at least 6 sq in. of flow area is available.

c) If b) above cannot be guaranteed, a second relief port, identical to the one mounted on the valve box, needs to be installed on the horizontal cold box vacuum shell.

d) The compressor system with common high pressure header will not be capable to supply gas to the break in the line at a rate which exceeds the capability of the relief port.